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R. D. NEIFELD

AUGUST 1995

US ARMY ARMAMENT RESEARCH,
DEVELOPMENT AND ENGINEERING CENTER
CLOSE COMBAT ARMAMENTS CENTER
BENÉT LABORATORIES
WATERVLIET, N.Y. 12189-4050

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13. ABSTRACT *(Maximum 200 words)*

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SIMPLER J_{Ic} TEST AND DATA ANALYSIS PROCEDURES FOR HIGH STRENGTH STEELS

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13. ABSTRACT *(Maximum 200 words)*

Tests of five medium and high strength steels were used to investigate some prospective simplifications in J_{Ic} test and data analysis procedures. Three-point bend specimens with material strengths of 500 to 1500 MPa and nominal thickness of 10 mm were tested at room temperature. The investigation included (1) J_{Ic} tests using measured crack-mouth displacement to calculate load-line displacement based on an expression that relates the two displacements; (2) a simple zero-point adjustment for J versus Δa curves, whereby certain intermediate Δa values are shifted to the blunting line to correct for errors at low values of Δa; and (3) a comparison of Δa and J_{Ic} results from the load-drop method, which gives a simple measure of crack growth after maximum load, with results from the usual unloading compliance method. The various results and comparisons are discussed in relation to their usefulness as a general J_{Ic} test procedure for a variety of materials, or a limited use test for certain materials. Two specific test and data analysis procedures are proposed for general use in J_{Ic} testing, as follows:

(1) A new expression is described that calculates load-line displacement for the bend specimen from measured crack-mouth displacement, for a range of a/W values and strain-hardening exponents. The expression makes possible a single-displacement unloading compliance J_{Ic} test for the bend specimen, using a single, standard, crack-mouth clip gage.

(2) A simple zero-shift procedure is proposed for general use with J_{Ic} tests and for addition to ASTM Method E-813. The procedure adjusts the zero point of Δa so that on average the Δa values lie on the blunting line over the J-range of 20 to 60 percent of the provisional fracture toughness, J_Q. The adjustment calculations can be done with a calculator or a few lines of computer code.

14. SUBJECT TERMS
J-Integral Fracture Toughness, Fracture Mechanics, High Strength Steel, Crack-Mouth Displacement, Unloading Compliance, Three-point Bend Specimen

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CURVATURE-INDUCED MOTIONS OF 60-MM GUNS
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13. ABSTRACT *(Maximum 200 words)*

In recent years, great strides have been made regarding the identification of the dominant loads that cause beam-type vibrations in tank cannons during ballistic operation. These motions infringe upon shot accuracy because at projectile disengagement the muzzle's kinematic state may compromise the projectile's intended flight path. A more subtle point involves the sources of loading the bore profile of the gun tube itself. While curvature-induced loads due to gravity droop are known to have little effect on gun motions, a similar claim in regard to center line profile produced by other conditions (manufacturing, thermal flexure, etc.) cannot be made. Very little testing or modelling has been conducted to establish the severity of this condition. This lack of data was the driving force behind the development of a set of controlled laboratory tests and the modelling simulations to study these relationships. Tests conducted on two 60-mm gun tubes with different profiles have been reported previously. In the current phase of this investigation, the modelling aspects are addressed. The mathematical relationships regarding load functions for beam vibration and the statistical aspects of curvature estimations are presented. These simulations mimic test results very well, thus establishing the worth of Benét Laboratories' Uniform Segments Gun Vibration Model. It is apparent that the tubes modelled are not dynamically similar with regard to their transverse motions during operation. The muzzle motion of the tube processing the most curvature is greater than and more sensitive to orientation than the straighter tube. The data indicates their effect and the modelling results confirm that shape and orientation have a significant effect upon gun motion and quite presumably accuracy.

14. SUBJECT TERMS
Gun Vibration, Vibration Modelling, Modal Analysis, 60-mm Guns, Gun Accuracy, Bore Curvature Sensitivity, Non-uniform Beam Vibration Modelling

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A REVIEW OF WELDMENT FAILURE MODES AND WELDABILITY TESTING METHODS

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13. ABSTRACT *(Maximum 200 words)*

An engineering study was conducted that reviewed typical weldment failure modes and the types of weldability test procedures currently used to predict behavioral response of a material that is to be welded. In comparing the design effectiveness of these tests, each has certain inherent technical advantages/disadvantages associated with it. The tests, if used appropriately, can save untold time and costs associated with poorly welded structures/components that fail in service prematurely. They are divided into two major categories, direct and indirect, related to the test methodology or procedure used to generate results. Specifically, direct tests make use of actual weldments, while indirect tests utilize basic metallurgical principles to predict weld behavior. From this study, it should be apparent that determining what the most appropriate weldability test procedure is for obtaining useful results for a given situation is critical to the success of that test.

14. SUBJECT TERMS
Weldability, Hot Cracking, Cold Cracking, Heat-Affected Zone

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A REVIEW OF RADIAL FORGING TECHNOLOGY INCLUDING PREFORM DESIGN FOR PROCESS OPTIMIZATION

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13. ABSTRACT *(Maximum 200 words)*

The Engineering Research Center for Net Shape Manufacturing (located at Ohio State University, Columbus, Ohio) was contracted by Benet Laboratories to investigate the rotary forging operation at Watervliet Arsenal. They were asked to make recommendations on how to optimize the shape and size of the starting material (preform) prior to forging which would reduce or eliminate variations in mechanical properties along the length of the resulting forging. Based on the data supplied by Benet Laboratories, the study resulted in recommendation of a two-step preform design. This was a preliminary recommendation and further testing was suggested to separate the effects of forging reduction from post-forging heat treatment.

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13. ABSTRACT *(Maximum 200 words)*

A program has been completed in which the thermal properties of 12 instrumented 120-mm tank rounds were measured as a function of varying ambient temperature. This report describes the test procedure, results of the test, and preliminary conclusions. The primary technical objective of the program was to determine the thermal responsiveness (in terms of time) of 120-mm tank rounds to varying ambient temperature conditions. The overall purpose of this report is to document program efforts. This report provides a reference for future work on the thermal characteristics of 120-mm M256 cannon tank ammunition.

14. SUBJECT TERMS
Thermal Emulator, 120-mm Tank Ammunition, Thermal Responsiveness, Instrumented Rounds, M1A1 Tank

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13. ABSTRACT (Maximum 200 words)

The vertebrate brain is explained as an assemblage of neurons, each responsive only to those afferent upon it. Thought is shown to proceed without a homunculus.

14. SUBJECT TERMS
Brain, Vertebrate, Homeostat, Thinking

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4. TITLE AND SUBTITLE
A STRESS FACTOR METHOD FOR PERFORATED MUZZLE BRAKE DESIGN

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6. AUTHOR(S)
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13. ABSTRACT (Maximum 200 words)

A perforated muzzle brake consists of a set of vents drilled through the wall of a cannon near the muzzle to reduce the impulse transmitted to the mount. The vented structure must support both the tube pressure and the pressure acting on the vent surfaces that produces the braking force. This report presents a method for estimating the maximum Von Mises stress within the structure. The results agree to within 10 percent of those from a more detailed finite element calculation.

14. SUBJECT TERMS
Gun, Muzzle Brake, Cylinder With Multiple Holes, Stress Factors

15. NUMBER OF PAGES
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EVALUATION OF THE "SOFT-RIDE" MUZZLE REFERENCE SYSTEM COLLIMATORS

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6. AUTHOR(S)
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13. ABSTRACT (Maximum 200 words)

This report presents the results of a series of tests used to evaluate two experimental "Soft-Ride" Muzzle Reference System Collimators (MRSCs). These MRSCs were designed as potential replacements for the MRSC used on the M1A1 Abrams tank. They would be used in the event that the firing shock of future ammunition became too severe for the M1A1 MRSC. Testing consisted of non-firing environmental tests, as well as hardstand and vehicle firing tests. The MRSCs were evaluated based upon their boresight retention accuracy and their ability to attenuate the firing load experienced by the MRSC optics. Results indicate that both "Soft-Ride" MRSC configurations can significantly attenuate the firing loads seen by the MRSC optics, however, only the banded configuration provides accuracy comparable to the M1A1 MRSC.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Muzzle Reference Systems, Collimators, M1A1 Abrams Tank, Boresight, 120-mm M256 Tube, Cannon Tubes, Muzzle Boresight Device, Dynamic Strain, Dynamic Strain Waves	47
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4. TITLE AND SUBTITLE
DESIGN OF A FATIGUE-RESISTANT PRESS USED TO CONTAIN 3,000 KIPS OF END LOAD AS A RESULT OF HIGH PRESSURE CYCLIC TESTING OF OPEN-ENDED CYLINDERS

5. FUNDING NUMBERS
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6. AUTHOR(S)
Michael J. Audino and Joseph A. Kapp

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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13. ABSTRACT (Maximum 200 words)

To determine the safe service life of cannon tubes, several samples must be cyclically tested to failure. Since testing these large diameter, open-ended cylinders requires pressures as high as 100 Ksi, the fatigue-loading conditions on the testing equipment are very demanding. One method for reacting the very high-end loads associated with testing these open-ended cylinders is through the use of an external press.

The press design discussed in this report deals with the design procedures involved in developing an infinite life press that can react end loads as high as 3000 kips. This press design involves the use of two low deflection platens connected by two high strength posts.

To design an infinite life threaded post, several methods of fatigue life enhancement can be applied. The most effective method of life extension is to preload the threaded post producing a high mean stress, but reducing the alternating stress or stress amplitude. This avenue of enhancement became the method of choice. Producing sufficient preload on a post with a diameter of 7 inches and a length of 115 inches by mechanical means requires torque-producing equipment presently available. By using electric heating elements inserted at the center of the posts, the posts can be expanded and the preload applied.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Safe Service Life, Soderberg Criteria, Stress Amplitude, Alternating Press	21
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NOTCH-TIP DAMAGE AND TRANSLAMINAR FRACTURE TOUGHNESS MEASUREMENTS FROM CARBON/EPOXY LAMINATES

5. FUNDING NUMBERS
AMCMS: 6111.02.H611.1
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6. AUTHOR(S)
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13. ABSTRACT (Maximum 200 words)
Notched [0/+45/90/-45] carbon/epoxy laminates were used to study translaminar fracture, where through-thickness cracking propagates across fibers and laminae. Radiographs of damage were compared with crack growth determined from load-versus-deflection plots using elastic fracture mechanics. Comparison of damage at the notch tip with fracture mechanics evaluations identified some material/test conditions for which a critical value of fracture toughness is a useful concept. For other conditions, the extent of damage in the specimen showed that the concept of fracture toughness is not directly applicable.

14. SUBJECT TERMS
Carbon/Epoxy, Laminates, Composite Materials, Notch Damage, Radiography, Fracture Mechanics, Fracture Toughness

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CHROMIUM/MOLYBDENUM ALLOY PLATING PART I:
THE ELECTRODEPOSITION OF LOW CONTRACTION CHROMIUM/
MOLYBDENUM ALLOYS USING UNIPOLAR (ON/OFF) PULSE PLATING

5. FUNDING NUMBERS
AMCMS: 6111.02.H611.1

6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

The microstructure and mechanical properties of a pulse-plated low contraction (LC) chromium/molybdenum (Cr/Mo) alloy deposit were evaluated and compared to both pulse-plated LC chromium and direct (dc)-plated LC chromium. Molybdenum concentrations as high as approximately 2.4 percent were obtained at a pulsing frequency of 5 Hz (100 ms on-time/100 ms off-time). This represents nearly a 300 percent increase over the percent molybdenum obtained in a dc-plated LC Cr/Mo alloy deposit. However, pulse-plated LC Cr/Mo deposits were generally poor in quality with deposits that were frequently cracked and nodular in appearance. Hardness values as high as 900 KHN (50 gm load) were obtained for the pulse-plated LC Cr/Mo alloy deposits. This hardness represents an 18 percent increase over the maximum reported hardness obtained in a dc-plated LC chromium deposit. The maximum cathode current efficiency (CCE) obtained while pulse plating an LC Cr/Mo alloy was 7.3 percent. This is nearly 52 percent less than the reported CCE obtained when dc plating LC chromium.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Chromium/Molybdenum Alloy, Aqueous, Pulse, Electrodeposition	13
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CALCULATIONS VIA SUCCESSIVE APPROXIMATIONS OF STRESS AND STRAIN DISTRIBUTION IN THICK-WALLED CONCENTRIC TUBES DUE TO A RADIAL TEMPERATURE GRADIENT

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

When thick-walled tubes are subjected to radial temperature gradients, cooler portions of the tubes impose constraints on the thermal expansion of hotter segments. (For example, in an internally heated tube, outer portions of the tube contain the expansion of the inner layer.) Constraint of the thermal expansion results in triaxial stress and strain distributions. A sequence of successive approximations has been used to calculate such stress and strain fields, while accounting for the mutual effect between the stress and strain fields, as described by the constitutive equations. Equilibrium is satisfied in all three mutually orthogonal coordinate directions, and compatibility (or conservation and continuity of matter) requirements are being complied with. Temperature dependence of the modulus of elasticity of the material is accounted for. The Mises' numbers field is computed to detect potential yielding. The total strain (thermal and elastic), which at the boundaries (inner and outer diameter surfaces and the axial ends of the tube) represents the dilation of the tubes, is also calculated.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Thick-Walled Tubes, Thermal Dilation, Temperature Gradient	18
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QUALIFICATION OF M256 BREECHBLOCK WELD REPAIR

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

A more engineered approach was taken to qualify an M256 breechblock weld repair procedure. The approach consisted of (1) identifying the principal areas requiring weld repair, (2) identifying a weld procedure and material, (3) preparing weld repair specimens, and (4) accumulating a shock and vibration history similar to that expected in service.

14. SUBJECT TERMS
M256, Breechblock, Welding, Repair

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STANDARDS FOR ORDNANCE MATERIALS; DYNAMIC FRACTURE AND ENVIRONMENTAL CRACKING APPLICATIONS

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

Two difficult and very different service conditions for Army ordnance, dynamic fracture and environmentally-assisted cracking, result in surprisingly similar approaches for fracture testing standards.

14. SUBJECT TERMS
Ordnance Materials, Dynamic Fracture, Crack Arrest
Environmental Cracking, Fracture Mechanics

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MATERIALS ANALYSIS OF 155-MM IMPROVED CONVENTIONAL ARMAMENT SYSTEM (ICAS) CANNON, TUBE SERIAL NO. XP-1

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6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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13. ABSTRACT *(Maximum 200 words)*

A materials analysis was performed on an experimental 155-mm Improved Conventional Armament System (ICAS) Cannon, Serial No. XP-1. The cannon experienced a malfunction during test firing at Aberdeen Proving Ground (MD), Range 18. The analysis included visual examination, chemical composition determination, metallographic examination, and mechanical property determination. It was determined that the tube material did not contribute to the malfunction. An adiabatic shear zone was observed indicating the tube was subjected to a localized, excessively high, rapidly applied load that was beyond the strength capabilities of the tube material.

14. SUBJECT TERMS
Gun Tube, Adiabatic Shear Zone, Failure Analysis

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LIQUID PROPELLANT PROTOTYPE CANNON:
PERFORMANCE OF THE WEAPON'S RECOIL SYSTEM

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*
The liquid propellant version of the Advanced Field Artillery System, which incorporated a tank-style mount and recoil system, was tested at the Wright-Malta Test Center (Malta, NY) and Yuma Proving Ground (Yuma, AZ) in late 1992. This report details the performance of the recoil system and compares the results to Benét Laboratories' recoil system modelling code.

14. SUBJECT TERMS
Advanced Field Artillery System, Recoil Brake Analysis, Recoil Brake Performance, Liquid Propellant Artillery Gun, Data Reduction, Shock Absorbers

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YIELD-BEFORE-BREAK FRACTURE MECHANICS ANALYSIS OF HIGH STRENGTH STEEL PRESSURE VESSELS

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

Case study examples of fracture mechanics testing and analysis of Ni-Cr-Mo high strength steel cannon tubes are presented. The testing and analysis include significant plastic deformation accompanying fracture, which often occurs when high pressure is applied to high toughness steel pressure vessels. The analysis is based on a comparison of the size of the Irwin crack-tip plastic zone with the remaining ligament of the tube in the critical fatigue crack area that causes final failure. The results of the study show that the type of final failure can be predicted as either a relatively safe yield-before-break failure or a less safe running-crack type of failure for a variety of material, configuration, and loading conditions.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Pressure Vessels, Fracture Mechanics, High Strength Steel, Plastic Yielding, Fatigue Failure	19
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EXPERIMENTAL HEAT TREATMENT OF BERYLLIUM COPPER ALLOY

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13. ABSTRACT (Maximum 200 words)

A cold-rolled beryllium copper alloy, in bar form, was experiencing deformation (bowing) during machining. Several experimental heat treatments were performed in order to develop a procedure that would alleviate this condition. These treatments consisted of (1) an age-hardening (overaging) and (2) a solution treatment and age-hardening. The minimum desired ultimate tensile strength (UTS) value was achieved in both heat-treating experiments conducted. For the age-hardening experiment, any aging time between one-half hour and two hours would obtain the desired UTS. For the solution treatment and age-hardening experiment, aging for one-half hour or greater at 500°F would fulfill the UTS requirement. Our recommendation for the remaining beryllium copper bars was a one hour age-hardening at 900°F.

14. SUBJECT TERMS
Beryllium Copper, Heat Treatment, Age-Hardening, Overaging

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13. ABSTRACT *(Maximum 200 words)*

A systematic study of the rate of convergence, cpu time, and accuracy of a numerical box-counting and a numerical correlation integral algorithm to Euclidean point sets, Koch constructions, and a symmetric chaotic mapping is described.

14. SUBJECT TERMS
Fractals, Multifractal Measures, Box-Counting Algorithms, Correlation Integral Methods, Numerical Multifractal Analysis

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4. TITLE AND SUBTITLE
AUTOMATED WELDING OF ROTARY FORGE HAMMERS

5. FUNDING NUMBERS
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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

The process development and implementation of an automated welding system used for repairing rotary forge hammers was performed by Benet Laboratories under a Manufacturing Methods and Technology project at Watervliet Arsenal. Two welding technologies were evaluated in the project, automated flux-cored wire-feed welding by the metal inert gas (MIG) process and powdered metal feed welding by the plasma transferred arc (PTA) process.

Initially, two development contracts were established and executed to determine the feasibility of and welding parameters necessary for hammer repair. Both contracts involved welding representative test samples to determine the optimum parameters for deposition rate and quality, and finally utilizing these parameters to weld-overlay actual rotary forge hammers. The hammers were then returned to Watervliet Arsenal for testing in production runs.

Based on encouraging results generated during the project, the flux-cored wire-feed welding method has been implemented at the Arsenal and is the current production welding method used for hammer repair and restoration.

14. SUBJECT TERMS
Plasma Transferred Arc (PTA) Welding, Metal Inert Gas (MIG) Welding, Metal Powder, Rotary Forge Hammers, Hardfacing

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4. TITLE AND SUBTITLE
SERVO CONTROL USING SWITCHES FOR DISCRETE POSITIONAL FEEDBACK

5. FUNDING NUMBERS
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6. AUTHOR(S)
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12a. DISTRIBUTION / AVAILABILITY STATEMENT
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13. ABSTRACT *(Maximum 200 words)*

This report describes an approach for providing and/or assisting in the positional control of a one degree-of-freedom servo-mechanism *using switches*. The switches, positioned along the path of a moving mechanism, can also be simulated using continuous feedback sensors for certain applications. Real time feedback of the discrete time at which each switch is tripped during motion is provided to the controller. Based on this time-position information, *constant motor forces to be applied between switches* are determined to sustain and complete the required repositioning task. A definitive control procedure is not presented here, but rather a promising one that may have important applications as we have found in our work. Also, the method is not intended to compete with more sophisticated and complicated approaches using higher component quality and quantity and computer power. On the contrary, one of the intended goals is to go somewhat the other way to make use of existing or even less expensive components. The main contribution that we make to this overall control technique is to introduce and use *probability and statistical concepts in determining the switch locations and the required real time motor forces*. A probabilistic approach is needed because of the uncertainty in the actual position and velocities of the mechanism as it travels between switches. These uncertainties in turn are derived from uncertainties in the disturbing forces that are encountered during any given motion cycle. In this report, we develop the theory for a statistically-based approach for control using switches. We then verify the results using simulation and experimentation. In our experimental work, we applied our techniques to the ramming mechanism of a large caliber tank autoloader with excellent results. From our experimental work, we also developed some modifications to the theoretically-derived control procedure to improve the overall response.

14. SUBJECT TERMS
Servo Control, Positional Feedback, Switches

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4. TITLE AND SUBTITLE
METALLURGICAL EVALUATION OF 25-MM M242 BUSHMASTER GUN TUBES, SERIAL NOS. 12373 AND 12374

5. FUNDING NUMBERS
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6. AUTHOR(S)
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13. ABSTRACT (Maximum 200 words)

A metallurgical evaluation of two 25-mm M242 Bushmaster gun tubes, Serial Nos. 12373 and 12374, was performed. The evaluation included visual examination, mechanical property determination, scanning electron microscopy, metallographic examination, and chemical composition determination. Based on the hardness values, chemical composition, and microstructure observed, the two gun tubes appeared to have been processed correctly. An area toward the muzzle end of Serial No. 12373 displayed a lower hardness and an altered microstructure that was likely due to overheating during firing. Uranium, aluminum, iron, and zinc were deposited throughout both gun tube bores.

14. SUBJECT TERMS
Malfunction Investigation, Bushmaster, 25-mm Gun Tubes, Nitriding, Depleted Uranium

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4. TITLE AND SUBTITLE
THE EFFECTS OF FATIGUE LOADING FREQUENCY ON FATIGUE LIFE OF HIGH-STRENGTH PRESSURE VESSEL STEELS

5. FUNDING NUMBERS
AMCMS No. 6111.02.H611.1
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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

Bend specimens of high-strength pressure vessel steel were tested in bending fatigue to failure at 1.5, 15, 30, and 75 Hz fatigue loading frequencies. In the 1.5 to 15 Hz range, there was no discernible difference in the frequency effect on fatigue life. However, in the 30 to 75 Hz range, there was a definite increase in fatigue life compared to the lower range of frequency. The average increase in fatigue life over the stress range was a factor of 10 greater than the life at the lower frequency range. This factor increased at lower stresses and decreased at higher stresses, but even at the highest stresses tested, the increase was significant, about 5 to 1. This indicates that the frequency effect is more effective at high-cycle fatigue and diminishes with low-cycle fatigue. A model for fatigue life deterioration caused by superimposition of loads under different frequencies is introduced.

14. SUBJECT TERMS
Fatigue Life, High Strength, Pressure Vessels, Steel, Frequency

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FATIGUE LIFE TESTS FOR THE MUZZLE REFERENCE SYSTEM COLLIMATOR ON THE 120-MM M256 CANNON TUBE

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6. AUTHOR(S)
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12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A laboratory fatigue life test system was developed to obtain comparative life data for the muzzle reference system collimator on the 120-mm M256 cannon tube. A fatigue load was established which, although only indirectly shown to correspond to the service loading, is believed to provide valuable comparative life data for different means of fastening key components of the collimator. Fatigue lives were measured for various means of fastening, including different configurations of electron-beam welding and different sizes and types of high strength screws. Using the S-N fatigue life approach, consistent descriptions of the fatigue life of the muzzle reference system collimator could be made.

14. SUBJECT TERMS
Fatigue Life, Electron-Beam Weld, Fasteners, Cannon Tube, S-N Curve, Muzzle Reference System

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STRESS INTENSITY FACTOR AND LOAD-LINE DISPLACEMENT EXPRESSIONS FOR THE ROUND BAR BEND SPECIMEN

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13. ABSTRACT *(Maximum 200 words)*

New wide-range expressions for stress intensity factor and load-line displacement for three-point bend fracture tests with the round bar specimen are described.

14. SUBJECT TERMS
Fracture Mechanics, Round Bar, Stress Intensity Factor, Load-Line Displacement, Fracture Toughness, Three-Point Bending

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13. ABSTRACT *(Maximum 200 words)*

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14. SUBJECT TERMS
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4. TITLE AND SUBTITLE
AUTOMATED DATA BASE OF MECHANICAL AND PHYSICAL PROPERTIES FOR GUN STEEL

5. FUNDING NUMBERS
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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

An automated data base of mechanical and physical properties for gun steel has been developed. The initial data base contains information for several gun systems and components with the available information including strength, fracture toughness, chemistry, and other mechanical properties. The data contents are available for publishing periodic summaries of the data-base results.

14. SUBJECT TERMS
Data Base, Gun Steel, Mechanical Properties, Physical Properties

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12a. DISTRIBUTION / AVAILABILITY STATEMENT
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13. ABSTRACT *(Maximum 200 words)*

Local fractal dimensions $\alpha(x,\epsilon)$, which are closely related to "crowding indices" of individual islands and lakes formed by sectioning of fracture surfaces produced in Charpy impact testing of a high-strength and high-toughness steel (ASTM A723) alloy, have been determined by perimeter-yardstick analysis. In this type of analysis, the perimeter of an island or lake on a fracture surface section is measured at several different magnifications, and Richardson's equation is employed to determine the fractal dimension of the island or lake. Perimeter-yardstick analysis, which had not previously been applied to fracture surface analysis, yielded $\alpha(x,\epsilon)$-values ranging from 1.17 to 1.40 (mean: 1.28, standard deviation: 0.08) for Charpy fracture islands and lakes in ASTM A723 steel for ϵ-values near 1.3 10^{-4} cm. The mean $\alpha(x,\epsilon)$-value is consistent with the (global) fractal dimension of 1.25 obtained by slit-island analysis of the same fracture surface sections--a value typical of high-strength steel alloys previously studied. The island-to-island and lake-to-lake variations of the local fractal dimensions reflect real variations analogous to differences in the fractal dimensions of the coastlines of Norway and England. Either the fracture surfaces are fractally inhomogeneous or the range of $\alpha(x,\epsilon)$-values determines limits on the variation of the global multifractal dimensions D(q) and a(q).

14. SUBJECT TERMS	15. NUMBER OF PAGES
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4. TITLE AND SUBTITLE
EXPONENTS IN LIFETIME AND POWER SPECTRAL DENSITY IN SELF-ORGANIZED CRITICAL SYSTEMS

5. FUNDING NUMBERS
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13. ABSTRACT (Maximum 200 words)

Bak, Tang, and Weisenfeld (BTW) established that power-law frequency dependencies in the power spectral density (PSD) and size-effect modified power-law distributions of lifetimes are the fingerprints of self-organized critical systems. Jensen, Christensen, and Fogedby (JCF) clarified the ideas introduced by BTW and established the connection between the distribution of lifetimes and the PSD for the case of exponentially cutoff ("size-effect" modified) distributions of lifetimes. Here the (JCF) connection between the PSD and the distribution of lifetimes is established for sharp cutoff distributions, which supports the idea that the JCF connection holds for quite general "size-effect" modified lifetime distributions. The PSD may be expressed in terms of generalized hypergeometric functions in this case. A detailed discussion of the JCF connections is presented for a subset of values of the lifetime distribution exponent for which the generalized hypergeometric functions reduce to Fresnel integrals and sine and cosine integrals, which were the subject of a recent "Numerical Recipes" column. All calculations were performed in Mathematica.

14. SUBJECT TERMS
Self-Organized Phenomena, Hyperbolic Distributions, Power Laws, Fresnel Integrals, Sine Integrals, Mathematica

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FAILURE ANALYSIS OF 120-MM MORTAR BUSHINGS AND FIRING PINS

5. FUNDING NUMBERS
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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

A failure analysis was performed on several 120-mm mortar bushings and firing pins. The analysis entailed examining (1) the failed firing pins and bushings for conformance to drawing requirements, and (2) the material differences between the U.S.-made and the Israeli-made components. The evaluation included visual examination, metallographic examination, microhardness determination, chemical composition determination, and scanning electron microscopy. The firing pins essentially met the required material specifications. However, it could not be determined whether the bushings met the requirements due to the vagueness of the drawing specifications. There were no observable material differences between the U.S.-made and the Israeli-made firing pins. The U.S.-made bushings did have a larger grain size, and the inner diameter of the bushing showed a slight surface degradation and rougher topography than the Israeli-made bushing. This difference in the inner diameter was due to the machining process, wire electrical discharge machining, that was used to produce the U.S.-made bushings.

14. SUBJECT TERMS
Failure Analysis, 120-mm Mortar, Wire Electrical Discharge Machining, Remelt

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13. ABSTRACT *(Maximum 200 words)*

Experimental and theoretical investigations were made for swage autofrettaged partially plastic ASTM A723 steel cylinders with an outside diameter (OD) to inside diameter (ID) ratio of 2.75 and 74 percent overstrain. Residual stress radial distribution and angular stress distribution around the bore were analyzed using two position-sensitive x-ray diffraction stress analyzers. Theoretical calculation was made by implementing an interactive, iterative Lotus Works spreadsheet residual stress model on an IBM PC. The model was based on the classical solution to the elastic-plastic deformation problem of a symmetric thick-walled cylinder under internal pressure, including reverse yielding effect. Angular stress distribution data at the ID and OD indicated that non-axisymmetric deformation had occurred during yielding of the cylinders. Excellent agreement was obtained between experimental results and theoretical predictions, including the Bauschinger effect near the bore. By comparing experimental data with theoretical calculations for the 74 percent overstrained cylinders, the Bauschinger factor for the A723 steel was determined to be close to 0.5. Residual stress analysis for the entire cylinder is suggested in the future.

14. SUBJECT TERMS
Residual Stress, Swage Autofrettage, Bauschinger's Effect, Position-Sensitive Stress Analyzer, X-Ray Diffraction, Pressure Vessel, Reverse Yielding, Plastic Deformation

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FRACTURE ASSESSMENT OF 155-MM M284 BREECH RINGS

5. FUNDING NUMBERS
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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

A 155-mm M284 breech ring assembly was being laboratory fatigue tested when an earlier-than-expected malfunction incident occurred. The subject breech ring, Serial No. 1659, was the sixth to be tested out of a population of six. The previous five breech rings tested possessed fatigue lives ranging from 4444 to 6214 cycles-to-failure (N_f). This particular ring, tested under the same conditions as the previous five rings, failed in a brittle fashion after only 109 cycles. Mechanical and fracture toughness testing of Serial No. 1659 revealed that the ring had undergone an inadequate heat treatment, which resulted in extremely low values of fracture toughness.

14. SUBJECT TERMS
Fatigue Life, Breech Ring, Fracture Toughness

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ADAPTIVE FINITE ELEMENT METHOD I:
SOLUTION ALGORITHM AND COMPUTATIONAL EXAMPLES

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

An adaptive finite element method is developed to solve initial boundary value problems for vector systems of parabolic partial differential equations in one space dimension and time. The differential equations are discretized in space using piecewise linear finite element approximations. Superconvergence properties and quadratic polynomials are used to derive a computationally inexpensive approximation to the spatial component of the error. This technique is coupled with time integration schemes of successively higher orders to obtain an approximation of the temporal and total discretization errors. These approximate errors are used to control an adaptive mesh refinement strategy. Refinement is performed in space, time, or both space and time depending on the dominant component of the error estimate. A computer code coupling this refinement strategy and stable mesh movement has been written and applied to a number of problems. These computations confirm that proper mesh movement can reduce the computational efforts associated with mesh refinement.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Parabolic Differential Equations, Adaptive Finite Elements, Superconvergence, Error Estimation, Mesh Refinement, Mesh Movement	51
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4. TITLE AND SUBTITLE
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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

An adaptive finite element method is developed to solve initial boundary value problems for vector systems of parabolic partial differential equations in one space dimension and time. The differential equations are discretized in space using piecewise linear finite element approximations. Superconvergence properties and quadratic polynomials are used to derive a computationally inexpensive approximation to the spatial component of the error. This technique is coupled with time integration schemes of successively higher orders to obtain an approximation of the temporal and total discretization errors. Computational results indicate that these approximations converge to the exact discretization errors as the mesh is refined.

14. SUBJECT TERMS
Parabolic Differential Equations, Adaptive Finite Elements, Finite Differences, Superconvergence, Error Estimation, Error Decomposition

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FAILURE ANALYSIS OF 120-MM M256 GUN TUBE, SERIAL NO. 2416

5. FUNDING NUMBERS
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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

A failure analysis was performed on a 120-mm M256 gun tube, Serial No. 2416. The gun tube experienced a muzzle end failure while firing kinetic energy training ammunition. The analysis included visual examination, mechanical property determination, scanning electron microscopy, metallographic examination, and chemical composition determination. Based on the analysis, the gun tube material met or exceeded all drawing requirements. No evidence of pre-existing flaws was found on the fracture surface. The most probable cause for the failure was a bore obstruction that was present during firing.

14. SUBJECT TERMS
Gun Tube Failure, Shear Fracture, Microvoid Coalescence, 120-mm M256 Gun Tube

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EXPERIMENTAL METHODS IN RESIDUAL STRESS MEASUREMENT USING A POSITION-SENSITIVE SINGLE-EXPOSURE SCINTILLATION DETECTION SYSTEM

5. FUNDING NUMBERS
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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

In the Denver D-1000-A single-exposure position-sensitive scintillation detection (PSSD) system, surface residual stress measurement in any chosen direction is based on crystalline plane spacings determined in two directions normal to the surface made simultaneously in a single psi tilt. This technical allows fast, noncontacting, and nondestructive biaxial stress analysis. In this report, system performance is characterized by studying the noise, gain, and diffraction peak profiles as a function of diode array element. A four-point bend experiment was performed to determine the elastic constant of the 211 plane of body-centered cubic martensitic steel. Residual stress measurements were performed in several steel specimens and compared to measurements made on a similar system at Pennsylvania State University. Local software development allowed the single-exposure PSSD to run in a multiple-exposure mode for improved accuracy in biaxial stress analysis.

14. SUBJECT TERMS
Residual Stress, Biaxial Stress, X-Ray Diffraction, Position-Sensitive Scintillation Detector, Single-Exposure Technique

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CHROMIUM PLATING AND ELECTROPOLISHING SOLUTION ANALYSES BY ONLINE X-RAY FLUORESCENCE SPECTROSCOPY

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6. AUTHOR(S)

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13. ABSTRACT *(Maximum 200 words)*

Two increasingly important issues for the chemical processing industry are product quality and productivity. Traditionally, offline chemical analysis has been used to monitor both. The main disadvantage of offline analysis is the loss of time due to sampling, bringing samples to a lab, and waiting for results. Obvious efficiencies can be realized by continuous online chemical monitoring. The initial investment is high, but the return on investment can be very efficient process performance. X-ray fluorescence spectroscopy (online and offline) is investigated and evaluated as a means to quantitatively analyze metal finishing solutions such as actual chromium plating and electroplating solutions for chromium, sulfur, phosphorus, and iron. The identical experiment was conducted at three different manufacturers of this type of instrument, and included calibration, standardization, and analysis. Although this work has a specific objective related to chromium plating and electropolishing liquid samples, much information is related to and provided for other types of samples. Chemical analysis by x-ray fluorescence spectroscopy is nondestructive, applicable to multiple process streams (liquid or solid), and requires no dilutions. In addition, calibration, standardization, and maintenance are minimal. For the specific metal finishing applications discussed, the resultant data do not suggest that this online monitoring technique is useful at this time, but future work may show this technique to be practical.

14. SUBJECT TERMS

Chemical Analysis, X-Ray Fluorescence, Online Analysis, Liquid Samples, Solid Samples, Chromium Plating Solutions, Electropolishing Solutions, Chromium Analysis, Sulfur Analysis, Iron Analysis, Phosphorus Analysis

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FATIGUE LIFE ANALYSIS AND TESTS FOR THICK-WALLED CYLINDERS INCLUDING EFFECTS OF OVERSTRAIN AND AXIAL GROOVES

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

A fracture mechanics-based fatigue life analysis was developed for pressurized thick-walled cylinders autofrettaged by overstrain and with one or several semi-elliptical-shaped axial grooves at the inner diameter. The fatigue life for a crack initiating at the root of the groove was calculated for various cylinder, groove, and crack configurations and for different material yielding conditions. Comparisons were made with fatigue crack growth and laboratory life results from A723 thick-walled cylinders in which cannon firing tests were first performed to produce axial erosion grooves, followed by cyclic hydraulic pressurization to failure in the laboratory. The life analysis, with an initial crack size based on the expected pre-existing defects, gave a good description of the crack growth and fatigue life of the tests for cylinders with and without grooves. General fatigue life calculations summarized important and configurational effects on the fatigue life design of overstrained cylinders, including effects of material yield strength, cylinder diameter ratio, stress concentration factor, and initial crack size.

14. SUBJECT TERMS
Fatigue Life Analysis, Thick-Walled Cylinders, Stress Concentration, Fatigue Tests, Erosion, Autofrettage, Residual Stress

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

This report describes the sensor technology and associated electronics of a monitor designed to detect the onset of a seizure disorder called *status epilepticus*. It is a condition that affects approximately 3 to 5 percent of those individuals suffering from epilepsy. This form of epilepsy does not follow the typical cycle of start-peak-end. The convulsions continue until medically interrupted and are life-threatening. The mortality rate is high without prompt medical treatment at a suitable facility. The report describes the details of a monitor design that provides an inexpensive solution to the needs of those responsible for the care of individuals afflicted with this disorder. The monitor has been designed as a cooperative research and development effort involving the United States Army Armament Research, Development, and Engineering Center's Benet Laboratories (Benet) and the Cerebral Palsy Center for the Disabled (Center), in association with the Department of Neurology at Albany Medical College (AMC). Benet has delivered a working prototype of the device for field testing, in collaboration with AMC. The Center has identified several children in need of special monitoring and has agreed to pursue commercialization of the device.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Neuronetworks, Epilepsy, *Status Epilepticus*, Monitors	9
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6. AUTHOR(S)
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13. ABSTRACT (Maximum 200 words)

An analysis is made of the meaning of the symbolically represented characteristics defined in certain dimensioning and tolerancing standards, authorized for use by the Department of Defense and the U.S. Army in the preparation of engineering drawings. The analysis is based on a comparison of the defined meaning in each of these standards as it relates to the defined meaning in the most current standard. The results show that the meaning and the associated tolerance has, in some cases, changed significantly as the standards evolved. These differences are identified and described.

14. SUBJECT TERMS
Geometric, Dimensioning, Tolerancing

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A FRACTURE MECHANICS ASSESSMENT OF THE 155-MM M284 MUZZLE BRAKE

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

A fracture mechanics analysis was conducted to determine the condemnation life assessment of the 155-mm M284 muzzle brake. The original assessment was found to be too conservative for a proper evaluation of fatigue life, based on a low estimate of fracture toughness derived from previous muzzle brake material. The updated analysis proved to be very accurate in predicting safe fatigue life and replacement of the muzzle brake after every second gun tube change, thereby saving considerably on muzzle brake replacement.

14. SUBJECT TERMS
Muzzle Brake, Fracture Toughness, Fatigue Life, In-House Inspection, Field Condemnation

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

A materials characterization was performed on hard chromium (HC) and low contraction (LC) chromium. The samples utilized in our analysis were sectioned from gun tubes electroplated in the vessel plating and production facilities at Watervliet Arsenal. The characterization compared chromium plate morphology and properties for (1) breech versus muzzle end of an LC chromium plated tube, (2) HC versus LC chromium, and (3) HC plated in the vessel plating versus production facilities. The analysis consisted of visual examination, metallographic examination, microhardness evaluation, x-ray diffraction, chemical composition determination, and scanning electron microscopy. Muzzle versus breech and hardness values were found to vary significantly within the LC chromium plated tube, while a slight variation was observed in the microstructure. The HC and LC chromium also displayed large differences in hardness and morphology. There were no observable differences in the HC plated in the two plating facilities.

14. SUBJECT TERMS
Hard Chromium, Low Contraction Chromium, Vessel Plating, Microcracking

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PARALLEL PARTITIONING STRATEGIES FOR THE ADAPTIVE SOLUTION OF CONSERVATION LAWS

5. FUNDING NUMBERS
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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*

We describe and examine the performance of adaptive methods for solving hyperbolic systems of conservation laws on massively parallel computers. The differential system is approximated by a discontinuous Galerkin finite element method with a hierarchical Legendre piecewise polynomial basis for the spatial discretization. Fluxes at element boundaries are computed by solving an approximate Riemann problem; a projection limiter is applied to keep the average solution monotone; time discretization is performed by Runge-Kutta integration; and a *p*-refinement-based error estimate is used as an enrichment indicator. Adaptive order (*p*-) and mesh (*h*-) refinement algorithms are presented and demonstrated. Using an element-based dynamic load balancing algorithm called tiling and adaptive *p*-refinement, parallel efficiencies of over 60% are achieved on a 1024-processor nCUBE/2 hypercube. We also demonstrate a fast, tree-based parallel partitioning strategy for three-dimensional octree-structured meshes. This method produces partition quality comparable to recursive spectral bisection at a greatly reduced cost.

14. SUBJECT TERMS
Adaptive Methods, Hyperbolic Systems of Conservation Laws, Massively Parallel Computation, Galerkin Finite Element Method, *h*-refinement, *p*-refinement, Load Balancing, Tiling, Domain Decomposition, Octree-Derived Meshes

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APPLICATION OF A RAPID QUENCH THERMOMAGNETIC ANALYZER TO AUSTEMPERED DUCTILE IRON

5. FUNDING NUMBERS
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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*
A thermomagnetic analyzer was fabricated to provide in-situ monitoring of isothermal decompositions of austenite in steels and related alloys. The analyzer provides a convenient and rapid means for establishing time-temperature-transformation characteristics of a ferrous alloy by cycling a given specimen through a series of thermal treatments and monitoring the transformations magnetically. The present report describes the apparatus and gives results on the transformation characteristics of austempered ductile iron (ADI). This analyzer was also used to investigate alternative processing procedures; the results indicate that an improved heat treatment is available for large ADI components.

14. SUBJECT TERMS
Thermomagnetic Analysis, Austempered Ductile Iron, Transformations, Austenite, Ferrite, Bainite

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AN HP-ADAPTIVE METHOD IN SPACE AND TIME FOR PARABOLIC SYSTEMS

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6. AUTHOR(S)
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13. ABSTRACT *(Maximum 200 words)*
We describe an adaptive method-of-lines *hp*-refinement algorithm in space and time for one-dimensional vector systems of parabolic partial differential equations. Solutions are calculated using Galerkin's method with a piecewise-polynomial hierarchical basis in space and singly-implicit Runge-Kutta (SIRK) methods in time. A posteriori estimates of the local spatial and temporal discretization error are used with a priori error estimates to control spatial and temporal enrichment. Computational results are used to compare and verify the utility of several variants of the basic *hp*-refinement procedure.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Adaptive Refinement, Finite-Element Methods, A Posteriori Error Estimation	37
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STRESS CONCENTRATION, STRESS INTENSITY, AND FATIGUE CRACK GROWTH ALONG EVACUATORS OF PRESSURIZED, AUTOFRETTAGED TUBES

5. FUNDING NUMBERS
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6. AUTHOR(S)
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13. ABSTRACT (Maximum 200 words)

A stress analysis has been conducted on a pressurized, fully or partially autofrettaged cylinder with a small diameter evacuator hole penetrating radially through the wall. Pressure was applied on the inside diameter (ID) of the tube, and all or part of this pressure was applied on the evacuator hole surfaces. Total hoop stress concentrations have been determined for a range of radial locations along the evacuator and stress intensity factors have been determined along a crack emanating from the evacuator hole. Fatigue crack growth rates, and hence crack profiles, were predicted at each of the radial locations. These predictions indicate that the critical location for the crack in a non-autofrettaged tube is at the ID, whereas in a fully autofrettaged tube, it is located approximately halfway through the wall thickness. Stress ratio $\sigma_{min}/\sigma_{max}$ has a significant influence on crack shape in autofrettaged tubes, however, it has a limited effect upon lifetime. The effect of axial residual stresses upon fatigue lifetime due to the autofrettage process has been described and an insignificant reduction in lifetime was a result of such stresses. Finally, the predicted profiles are compared with experimental observations of fatigue crack evacuators, and a limited comparison of predicted and actual lifetimes is presented. Good agreement has been observed in both comparisons.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Crack Growth, Fatigue Cracks, Cylinders, Evacuators, Cross-Bore, Fracture (Materials), Fracture Mechanics, Residual Stress, Stress Intensity Factor, Stress Ratio	24
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REPORT OF VISITING SCIENTIST ATTACHMENT OF DR. ANTHONY P. PARKER OF UNIVERSITY OF NORTHUMBRIA, U.K. TO BENÉT LABORATORIES JULY - AUGUST 1994

5. FUNDING NUMBERS
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6. AUTHOR(S)
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13. ABSTRACT (Maximum 200 words)

The results of a two-month visiting scientist attachment of Dr. Anthony P. Parker from the University of Northumbria at Newcastle, United Kingdom to the U.S. Army Armament Research, Development, and Engineering Center, Benét Laboratories are reported. A description is given of the arrangements for the visit, the technical topics addressed during the visit, and the status of the technical reports that give details of the results of the visit.

14. SUBJECT TERMS
Visiting Scientist, Fracture Mechanics, Metal Fatigue, Stress Analysis, Pressure Vessels

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SPECTRAL CHARACTERIZATION OF PULSED ULTRASOUND USING NEURAL NETWORKS

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6. AUTHOR(S)
Mark A. Johnson, Michael A. Cipollo, and R.D. Scanlon

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13. ABSTRACT *(Maximum 200 words)*

A novel nondestructive evaluation technique that uses the spectral signature of a pulsed ultrasound signal to identify metals had recently been abandoned because of the difficulty in interpreting the results. Traditional analysis is inconvenient to apply to this type of problem because of the complicated, noisy, and incomplete nature of the data. Neural networks provide a radically different approach to computation. These massively parallel systems provide a mechanism to extract pertinent information from input data while maintaining a high degree of fault tolerance. This report discusses design of a neural network system capable of accepting data from nondestructive test equipment and producing output relative to the quality of the sample being tested.

14. SUBJECT TERMS
Neural Networks, Nondestructive Testing, Ultrasonics, Signal Analysis, Parallel Processing, Transputers, Metals, Impurities

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THE ELECTRODEPOSITION OF LOW CONTRACTION CHROMIUM/MOLYBDENUM ALLOYS USING PULSE-REVERSE PLATING

5. FUNDING NUMBERS
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6. AUTHOR(S)
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13. ABSTRACT (Maximum 200 words)

The use of modulated pulse periodic reverse (pulse-reverse) current to electrodeposit a low contraction (LC) chromium/molybdenum alloy has been evaluated. When using one full pulse-reverse plating cycle, the percent molybdenum in the deposit increased almost 400 percent (from 1 to 4 percent) as the current in the reverse cycle was increased from 0 to 10 amps. However, when the pulse-reverse current was carried to six full plating cycles, the percent molybdenum in the deposit was not dependent upon the current and remained constant at about 1 percent. This is about the same percent molybdenum that could be expected in direct current-plated LC chromium/molybdenum alloy and about half the percent molybdenum that could be expected in an on/off pulse-plated LC chromium/molybdenum alloy.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Molybdenum, Chromium, Electroplating, Electrodeposition, Pulse, Pulse-Reverse	12
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